Increased Catch of Codling Moth (Lepidoptera: Tortricidae) in Semiochemical-Baited Orange Plastic Delta-Shaped Traps

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ABSTRACT Studies were conducted in apple, *Malus domestica* (Borkhausen), to evaluate the attractiveness of semiochemical-baited orange plastic versus the standard white plastic delta-shaped sticky trap in capturing adult codling moth, *Cydia pomonella* L. Initial field tests showed that both orange- and green-painted sex pheromone-baited traps caught more male codling moths than the unpainted white trap. An orange plastic trap caught a similar number of moths as the orange painted trap. The orange plastic trap caught significantly more moths in field tests than either a solid white plastic trap or a white plastic trap with an orange logo covering 25% of the surface of the trap. Trap color and light level (2.0 versus 6.0 lux) significantly impacted the proportion of male moths contacting and subsequently caught in sex pheromone-baited traps in a flight tunnel. A significantly higher proportion of moths flew directly into versus landing on the outside of orange than white traps. Capture of male moths flying into traps was reduced under the higher light level. Trap color did not influence the catch of female codling moths in traps baited with a combination of sex pheromone and pear ester in field tests or in traps baited with pear ester in the flight tunnel. The capture of female moths was reduced in the flight tunnel at the higher light level. We hypothesize that this effect of trap color on the capture of male codling moth is caused by both the lower overall reflectance and the absence of reflectance at wavelengths <560 nm in orange versus white traps.

KEY WORDS apple, *Cydia pomonella*, traps, monitoring

An optimal standardized trap design is vital in developing a useful monitoring system for codling moth, *Cydia pomonella* L. (Knight and Christianson 1999, Knight et al. 2006). A variety of sticky and nonsticky trap types have been evaluated for this important pest (Knodel and Agnello 1990, Vincent et al. 1990). However, in the western United States, a sticky cardboard wing trap has been the standard for 20 yr (Riedl et al. 1986). Recently, Knight et al. (2002) found that either a delta- or diamond-shaped trap baited with sex pheromone was more effective than the standard wing trap in laboratory flight tunnel and in field trials, and a white delta-shaped trap has become the new standard for monitoring codling moth in Washington State (Doerr et al. 2004).

Color is an important quality affecting the performance of the delta-shaped trap for both the capture of codling moth and nontargets (Knight and Miliczky 2003). Delta-shaped traps painted a glossy orange or green color caught significantly more codling moths than either painted or unpainted white traps. White delta-shaped traps consistently catch honey bees, *Apis mellifera* L., and frequent replacement of trap liners is required to maintain an effective and consistent trapping surface (Riedl et al. 1986, Knight et al. 2002). Use of dark-colored traps significantly reduced the catch of bees but increased the catch of muscoid flies (Knight and Miliczky 2003). Whether the differences in the capture of nontargets, such as bees and muscoid flies, between white and colored traps affects the cost or efficacy of monitoring codling moth in most orchards is unclear.

A number of biological and economic factors could affect growers' decisions to change the color of monitoring traps for codling moth. Additional information, however, is required to extrapolate the preliminary findings of Knight and Miliczky (2003). At present, the influence of trap color has only been reported for hand-painted sex pheromone–baited traps early in the season. The efficacy of commercially available, colored delta-shaped traps should be studied over the entire season to examine the consistency of this response across a range of daily temperatures and for both the overwintering and summer generations of moths. Studies examining codling moth's orientation behaviors and capture in white versus colored traps could show the mechanism of this effect more clearly and would be a useful prerequisite for further improvements in trap design. Recently, pear ester, ethyl (*E, Z*)-2,4-decadienoate, has been shown to be a useful kairomone attractant to monitor the seasonal phe-

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nology of both sexes of codling moth (Knight and Light 2005c). The effect of trap color on the catch of male and female codling moths in traps baited with pear ester has not been reported. Herein, we present results from a series of tests that examine these issues using an orange plastic trap.

Materials and Methods

Description of Traps and Orchards. Delta-shaped traps (28 by 20 cm) used in all experiments were supplied by Suterra (Bend, OR). Traps in 2004 were left either unpainted and reversed so that no logo was visible or painted with one of two high gloss paints: Spring Grass green 2327 or Pumpkin orange gloss 2411 (Krylon, Cleveland, OH). The two colors were characterized based on their value, chroma, and hue: green (4, 8, 5G) and orange (6, 14, 2.5YR) (Munsell Book of Color 1976). An orange plastic trap was evaluated in 2005. The color of this trap was characterized as value = 6, chroma = 12, and hue = 10R (Munsell Book of Color 1976). Tests in 2005 were conducted with both the standard white trap with a Suterra orange logo and with similar traps that were reversed so that the logo was not exposed. The orange Suterra logo covered 25% of the surface of the white trap and was the same color as the orange trap. All traps were attached to plastic poles and hung in the upper third of the tree canopy.

Field studies were conducted in three apple *Malus domestica* (Borkhausen), orchards during 2004–2005. Orchards were 30-yr-old mixed blocks of 'Delicious' and 'Golden Delicious' situated 5 km north of Moxee, WA (46°33′ N, 120°23′ W). Mean (SE) tree height in these orchards was 4.3 (0.2) m.

Field Trials. Experiment 1 compared moth catches in three trap types baited with the sex pheromone lure, CM L2 (Trécé, Adair, OK): painted orange and green traps and the white plastic trap with no logo. Twelve replicates of each trap type were placed in orchard 1. Thirty-six trap locations spaced 30–50 m apart were marked with flagging. Traps were randomized and placed in the orchard on 22 July 2004. Traps were checked on 26 July, 2, 9, 16, 23, and 30 August, and 8 September. Traps were rerandomized on each date.

Experiment 2 compared the effectiveness of the orange-painted and the orange plastic traps. Traps were baited with the CM-DA Combo lure loaded with both sex pheromone and pear ester (Trécé). Thirty trees spaced 25–35 m apart were flagged, and 15 replicates of each trap type were randomly placed in orchard 2 on 11 July 2005. Traps were checked on 18, 21, and 25 July and 1 August, and trap positions were rerandomized on each date. All moths were sexed.

Experiment 3 compared the effectiveness of the orange plastic versus the white plastic trap with no visible logo. Traps were baited with the CM L2 lure. Twenty trees spaced 25–35 m apart were flagged, and 10 replicates of each trap type were randomly placed in orchard 3 on 8 June 2005. Traps were checked on 15 June, rerandomized, and checked again on 22 June.

Experiment 4 compared the effectiveness of the orange plastic versus the white plastic trap with the orange Suterra logo. Traps were baited with the CM-DA Combo lure. Thirty trees spaced 25–35 m apart were flagged, and 15 replicates of each trap type were randomly placed in orchard 3 on 8 August. Traps were checked on 15 and 26 August and 1 September and rerandomized on each date. All moths were sexed.

Flight Tunnel Tests. The flight tunnel was constructed from 6-mm acrylic sheeting (1.66 m long, 0.57 m wide, and 0.57 m high). A 12-volt DC blower was used to pull air from the room (maintained at 22–24°C and 50–60% RH) into a plenum, through a charcoal filter, and through a series of screens before passing into the tunnel. Air flow through the tunnel was maintained at 0.25 m/s. Exhaust was expelled to the outside of the building. Traps were placed on a ring stand 0.31 m above the tunnel floor and 0.20 m from the entrance of the tunnel. Traps were baited with halobutyl gray septa loaded with either 0.1 mg codlemone (male tests) or 3.0 mg pear ester (female tests). Lures were pinned to the middle of the trap bottom and above the adhesive in all traps. Codlemone (97% purity; Aldrich Chemical, Minneapolis, MN) was added to the cup portion of the septa in a 200-μl aliquot of dichloromethane followed by another 200 μl of dichloromethane to ensure penetration of the material. Pear ester lures (CM-DA) were provided by Trécé.

Male moths ($<$36 h old) were obtained from the USDA laboratory colony reared on artificial diet and conditioned in constant light for 24–48 h at 21°C and 60% RH. Before testing, moths were placed in complete darkness for 30 min and then released individually from a petri plate placed on a 30-cm-high platform placed near the air outlet end of the tunnel. Moth behavior was recorded for up to 6 min or until the moth was caught in the trap. The occurrence of wing fanning, upwind flight, touching the trap, the location where the moth first contacted the trap, and moth capture in the trap were recorded for each moth. The location of first moth contact with the trap was categorized as the moth flying inside the trap or first landing on the outside of the trap.

Flight tunnel studies were conducted at two light levels: a low light level of 2.0 lux (Extech Instruments, Waltham, MA) provided by three incandescent 40-W red lights placed over the tunnel and a higher light level (6.0 lux) created by placing a single incandescent 40-W light facing the wall in the corner of the room 2.0 m from the flight tunnel. Four replicates of five male moths were flown consecutively to orange and white traps at one light level on each of six dates. New orange and white traps were tested alternately on each date, and light levels were alternated between dates.

Flight tunnel tests also compared the attractiveness of white and orange traps baited with a pear ester lure (CM-DA) to mated female moths under the same two light levels ($n = 9$). Trap color was alternated on each day, and each light level was run for 2 consecutive d. Tests were conducted with female moths presumed to have mated. Virgin pairs of male and female moths

Table 1. Influence of trap color on the capture of codling moth in sticky delta-shaped traps baited with sex pheromone (experiments 1 and 3) or a combination sex pheromone and pear ester lure (experiments 2 and 4)

Trap type	Mean (SE) moth catch per trap per time interval			
	Experiment 1	Experiment 2[a]	Experiment 3	Experiment 4[a]
Hand-painted green	18.4 (1.8)a	—	—	—
Hand-painted orange	20.4 (1.9)a	15.0 (1.9) [0.7 (0.2)]	—	—
Orange plastic	—	15.5 (1.6) [0.6 (0.1)]	3.6 (0.6)a	2.6 (0.6)a [0.5 (0.1)]
White plastic, no logo	11.6 (1.2)b	—	1.7 (0.4)b	—
White plastic, orange logo	—	—	—	1.3 (0.2)b [0.5 (0.1)]

Means within the same column followed by a different letter are significantly different at $P < 0.05$ (LSD test).
[a] Mean (SE) catch of female codling moths are shown in brackets.

were placed in 416-ml plastic cups in a room maintained at 25°C, 16:8 L:D, and >45% RH for 1 d before testing. Cohorts of five female moths were released each day in the flight tunnel at 1400 hours, and traps were checked the following morning at 0700 hours. All female moths caught in traps and remaining in the flight tunnel were dissected to determine their mating status (presence or absence of a spermatophore in their *bursa copulatrix*).

Spectral Reflectance. Trap samples (100 cm^2) were scanned with a Perkin-Elmer Lambda-9/19 spectrophotometer (Wellesley, MA) manufactured by Avian Technologies (Wilmington, OH). Trap surfaces were scanned at wavelengths from 360 to 830 nm with a monochromatic slit width set at 2 nm and operated at a scan rate of 120 nm/min.

Statistical Analyses. All count and proportional data were subjected to square root and angular transformations, respectively, to stabilize variances before analysis of variance (ANOVA) (Snedecor and Cochran 1967). Transitional probabilities of male flight behaviors and catch of female moths were analyzed with a 2 by 2 factorial ANOVA with trap color and light level as the main factors. The proportion of male moths captured that flew into versus landed on the outside of the trap was compared with a one-way ANOVA. Means were separated in significant ANOVAs with Fisher least significant difference (LSD). Linear contrasts were calculated in ANOVAs with a significant interaction term using Scheffé F method (Analytical Software 2003).

Results

Field Trials. Moth counts were significantly higher ($F = 10.2$; df = 2,249; $P < 0.0001$) in both the painted green and orange traps baited with sex pheromone versus the white trap in experiment 1 during 2004 (Table 1). Neither total ($F = 0.20$; df = 1,114; $P = 0.65$) nor female moth catches ($F = 0.02$; df = 1,114; $P = 0.88$) were significantly different between the painted orange and orange plastic traps baited with the combo lure in experiment 2. The orange plastic trap baited with sex pheromone caught significantly more codling moths ($F = 6.63$; df = 1,38; $P < 0.05$) than the solid white plastic trap in experiment 3. The orange plastic trap baited with the combo lure also caught significantly more total moths ($F = 5.19$; df = 1,88; $P < 0.05$) than the white plastic with the orange Suterra logo, but catches of female moths did not differ significantly in experiment 4 ($F = 0.00$; df = 1,88; $P = 1.00$).

Flight Tunnel Tests. All male moths exhibited wing fanning and upwind flight to the sex pheromone lure in flight tunnel tests. Trap color and light intensity were significant factors affecting moth contact and subsequent catch in traps (Table 2). A higher proportion of male moths contacted and were subsequently caught in orange versus white traps. A greater proportion of moths touched and were captured in traps under the lower light conditions (2.0 lux) red versus white light. The interactions between trap color and light level did not significantly impact moth capture.

Nearly one third of male moths contacting traps flew directly inside versus first landing on the outside of the trap. Both trap color and light level affected the proportion of moths flying inside of traps (Table 3). Fewer moths flew into white versus orange traps and under the higher light level. The interaction of trap color and light level was not significant.

Light level but not trap color affected the proportion of moths caught that flew directly into the trap. Fewer moths were captured under higher light levels.

Table 2. Influence of trap color and light levels on the response of male moths to a sex pheromone–baited trap placed in a flight tunnel

Trap color	Light level (lux)	Mean (SE) transitional probabilities		
		Upwind flight–trap contact	Trap contact–moth catch	Upwind flight–moth catch
White	2.0	0.82 (0.03)	0.81 (0.04)	0.66 (0.03)
Orange	2.0	0.88 (0.02)	0.85 (0.03)	0.75 (0.02)
White	6.0	0.58 (0.03)	0.50 (0.04)	0.29 (0.02)
Orange	6.0	0.64 (0.03)	0.65 (0.05)	0.42 (0.03)
ANOVA df = 1,92	Trap color (TC)	$F = 6.01, P < 0.05$	$F = 5.57, P < 0.05$	$F = 14.87, P < 0.001$
	Light level (LL)	$F = 84.26, P < 0.0001$	$F = 39.75, P < 0.0001$	$F = 168.08, P < 0.0001$
	TC × LL	$F = 0.00, P = 0.96$	$F = 1.91, P = 0.17$	$F = 0.52, P = 0.47$

Table 3. Influence of trap color and light levels on the proportion of male moths flying inside or landing on the outside of sex pheromone–baited traps placed in a flight tunnel

Trap color	Light level (lux)	Mean (SE) proportion of moths contacting trap that flew inside	Mean (SE) proportion of moths captured that	
			Flew into trap	Landed on outside of trap[a]
White	2.0	0.28 (0.05)	0.94 (0.05)	0.78 (0.05)a
Orange	2.0	0.38 (0.02)	0.95 (0.04)	0.80 (0.05)a
White	6.0	0.18 (0.04)	0.76 (0.10)	0.39 (0.04)c
Orange	6.0	0.28 (0.03)	0.79 (0.11)	0.62 (0.05)b
ANOVA	Trap color (TC)	$F_{1,92} = 8.08, P < 0.01$	$F_{1,77} = 0.02, P = 0.89$	$F_{1,91} = 5.86, P < 0.05$
	Light level (LL)	$F_{1,92} = 6.79, P < 0.05$	$F_{1,77} = 35.69, P < 0.05$	$F_{1,91} = 31.02, P < 0.0001$
	TC × LL	$F_{1,92} = 0.00, P = 0.95$	$F_{1,77} = 0.07, P = 0.79$	$F_{1,91} = 4.03, P < 0.05$

[a] Because of a significant interaction of trap color and light level, linear contrasts were calculated using Scheffe's F method, $P < 0.05$.

The interaction of trap color and light level was not significant. Moths landing on the outside of either trap type under the higher light level were caught at a lower proportion than moths under the lower light level. At the higher light level, moth capture efficiency was lower for white than orange traps. The proportion of moths captured that first landed on the outside of traps was significantly lower than for moths flying into the trap ($F_{1,167} = 20.90, P < 0.0001$).

Less than 20% of the female codling moths flown in the flight tunnel were captured overnight in traps baited with pear ester. All moths caught in traps or still in the flight tunnel were mated. Light level ($F_{1,32} = 8.55, P < 0.01$) but not trap color ($F_{1,32} = 0.02, P = 0.8$) affected female moth capture. The interaction of trap color and light level was not significant ($F_{1,32} = 0.78, P = 0.38$).

Spectral Reflectance. The spectral reflectance pattern of the orange plastic traps was very similar to the orange painted trap previously reported (Knight and Miliczky 2003). Reflectance of the orange trap was <10% at wavelengths shorter than 560 nm, increased rapidly at 560 nm, and reached a plateau of ≈60–70% beginning at 620 nm. In comparison, the white trap exhibited >75% reflectance at all wavelengths >420 nm.

Discussion

Trap color seems to be an important factor affecting the catch of male codling moth in sex pheromone–baited traps. Traps with lower spectral reflectance, especially at wavelengths <560 nm, catch significantly more moths than white traps that have high levels of reflectance at wavelengths >420 nm (Knight and Miliczky 2003). Trap color has also been reported to be a significant factor affecting catches of several other moth species (Hendricks et al. 1972; Agee 1973; McLaughlin et al. 1975; Childers et al. 1979; Mitchell et al. 1989). In general, the influence of trap color has been discussed in terms of attraction (i.e., moths are more strongly attracted to traps of certain colors). However, a positive correlation between the spectral sensitivity of a night-flying moth's compound eyes and the most effective trap color does not always exist (Agee 1973; Mitchell et al. 1989). For example, the spectral sensitivities of *Anticarsia gemmatalis* Hübner and *Spodoptera frugiperda* (J. E. Smith) (Mitchell et al. 1989) and *Heliothis zea* (Boddie) and *H. virescens* (F.) (Agee 1973) are high at wavelengths >360 nm, peak at 540–580 nm, and decline sharply at wavelengths >600 nm. However, moth catches in green versus white plastic bucket traps were either lower (Mitchell et al. 1989) or higher (Hendricks et al. 1972) with these respective pairs of moth species. Despite higher catches of male *H. virescens* in green bucket traps, fewer moths were caught in light traps emitting radiation primarily in the green versus UV range of the spectrum (Deay et al. 1965). Similarly, catches of codling moth were higher in green versus white traps (Knight and Miliczky 2003) and in light traps emitting wavelengths <560 nm versus traps with lights emitting a broader range of wavelengths (Marshall and Hienton 1938).

These contrary results suggest that an alternative mechanism to one of attraction to a specific color may influence moth catches in traps of different colors for some species. Nearly all night-flying moths are attracted to UV and violet-blue radiation (Muirhead-Thomson 1991). However, with some species, sex pheromone–baited traps that have low levels of reflectance in the 360- to 560-nm range may catch more moths because they are less visually disruptive of the sequence of anemotactic flight behaviors necessary for moth capture. For example, McLaughlin et al. (1975) found that black traps with low reflectance were more effective for *Trichoplusia ni* (Hübner) and *Pseudoplusia includens* (Walker) than bright yellow traps.

Trap color and light levels were significant factors affecting the proportion of moths contacting the trap. Male codling moths are primarily active at dusk, and visual cues are known to be an important factor affecting the close range orientation of males to females or synthetic lures (Castrovillo and Cardé 1979, 1980). Visual detection of the trap could be an important reason why significantly fewer males contacted white versus orange traps. Knight et al. (2002) found that male codling moths under low light levels generally land on the front opening of white sex pheromone–baited traps and walked inside toward the lure. We found this to be true for both white and orange traps under both light levels in this study. However, a greater proportion of males flew directly inside orange versus white traps, and this was a significant factor affecting the catch of moths. These data were consistent with our field studies.

Trap color and light levels did not affect the captures of female codling moth in delta-shaped traps in our study. The response of female codling moths to pear ester–baited traps can begin several hours before dusk (Knight and Light 2005b) and coincides closely with the circadian periodicity of oviposition (Riedl and Loher 1980). Studies using pear ester–baited interception traps found that traps painted white, green, orange, yellow, or blue caught significantly fewer female moths than clear traps, but catches of male moths did not differ between clear and these variously colored traps (A.L.K., unpublished data). Thus, we infer that orange and white traps may negatively impact the capture of female moths similarly.

The low numbers and proportions of female moths caught in our two field studies and in the flight tunnel with pear ester suggest that the delta-shaped trap is not an effective monitoring tool for female codling moths. Clear interception traps baited with a pear ester lure caught nine-fold more female moths during the season than a similarly baited white delta-shaped trap (A.L.K., unpublished data). Development of an improved trap for female moths should consider both color and geometry. Captures of female moths were significantly increased when a large horizontal surface was provided for females to land at some distance from the lure (Ioriatti et al. 2003, Knight and Light 2005b). Trap designs that include a larger opening and sticky horizontal surface should be studied.

Switching from white to orange traps to monitor codling moth has two major advantages: higher moth catches and lower catches of honey bees (Knight and Miliczky 2003). However, placing large white corporate logos on the sides of orange traps could minimize these advantages and should be evaluated first. The use of green traps has also been recommended (Knight and Miliczky 2003); but concern about their visibility in orchards has limited commercial development. The use of specific trap color and lure combinations has been suggested as a tool to minimize cross contamination of traps, i.e., pheromone contamination of kairomone-baited traps (Knight and Light 2005a).

Action thresholds for codling moth that trigger a recommendation to apply insecticides in orchards treated with sex pheromones are based on relatively low cumulative moth catches (1–4 moths/trap/time period) in white delta-shaped traps baited with either sex pheromone or pear ester (Knight et al. 2005b). Therefore, switching to a different trap/lure combination that could achieve even small increases in moth catches could significantly impact growers' pest management decision-making. Our data show that replacing white with orange traps to monitor codling moth will likely require a reassessment of action thresholds for this important pest.

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